2005 Deer Conference

August 21 - 25, 2005 - Chicago - Illinois, USA

THE POTENTIAL OF ELECTRIC EXHAUST GAS TURBOCHARGING FOR HD DIESEL ENGINES

F. Millo, F. Mallamo, E. Pautasso (POLITECNICO DI TORINO, ITALY)

G. Dellora, G. Ganio Mego (IVECO S.P.A., ITALY)

J. Bumby, S. Crossland (UNIVERSITY OF DURHAM, UK)

O. Ryder (HOLSET TURBOCHARGERS, UK)

L. Jaeger, L. Montali (IVECOMOTORENFORSHUNG LTD, CH)

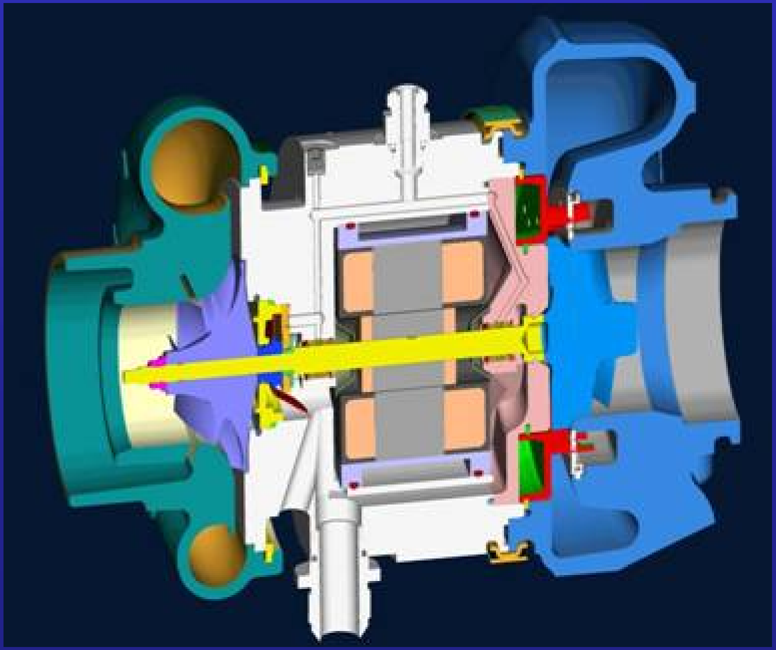
Presentation overview

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

INTRODUCTION

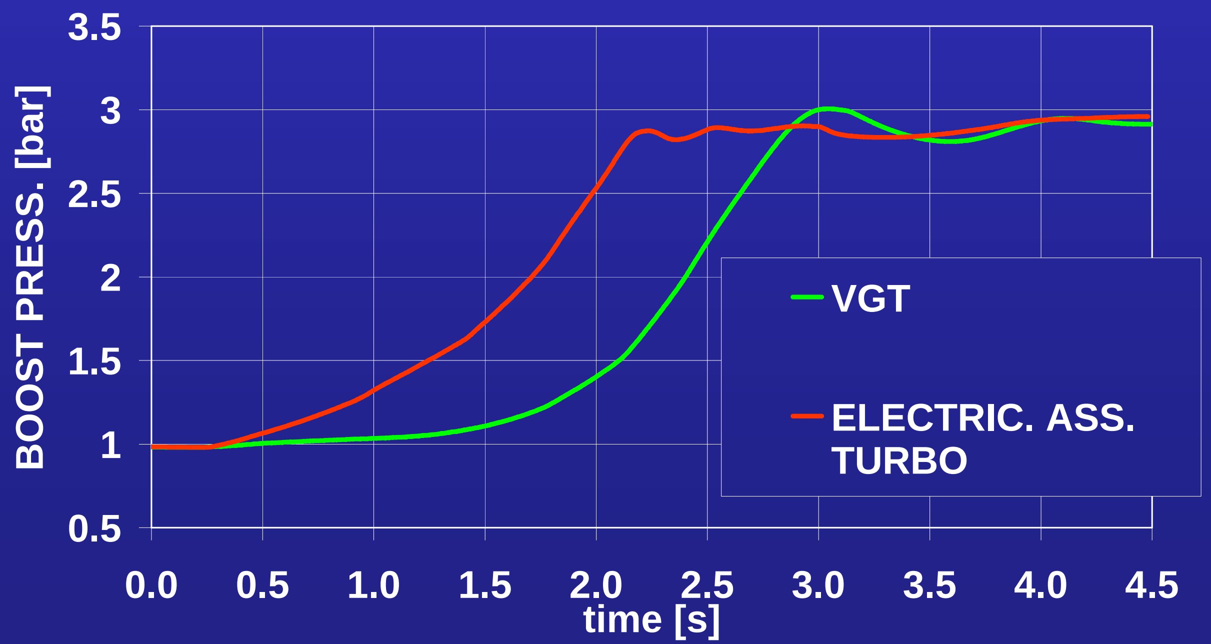
THE AIM OF THE RESEARCH PROJECT WAS TO ANALYSE THE POTENTIAL OF AN ELECTRIC ASSISTED TURBOCHARGER FOR A HEAVY-DUTY DIESEL ENGINE, REPLACING THE CURRENT VARIABLE GEOMETRY TURBINE WITH A FIXED GEOMETRY TURBINE AND CONNECTING TO THE TURBO SHAFT AN ELECTRIC MACHINE WHICH CAN OPERATE BOTH AS AN ELECTRIC MOTOR AND AS AN ELECTRIC GENERATOR



- **Introduction**
- **Contest**
- **Building the engine and vehicle model**
- **Analysis of possible fuel consumption reductions and performance enhancements**
- **Conclusions**
- **Continuation**

INTRODUCTION

THE ELECTRIC MACHINE OPERATES AS A MOTOR WHEN THE INTERNAL COMBUSTION ENGINE SPEEDS UP FROM IDLE AND AFTER GEAR SHIFTS IN ORDER TO HELP THE TURBOCHARGER TO ACCELERATE AND SO TO REDUCE THE TURBO-LAG, REDUCING PARTICULATE EMISSIONS DURING TRANSIENTS, ENHANCING THE ENGINE PERFORMANCE AND SO ALLOWING ENGINE DOWNSIZING.



- **Introduction**
- **Contest**
- **Building the engine and vehicle model**
- **Analysis of possible fuel consumption reductions and performance enhancements**
- **Conclusions**
- **Continuation**

INTRODUCTION

THE ELECTRIC MACHINE OPERATES AS A GENERATOR WHEN IT IS POSSIBLE TO EXTRACT FROM THE EXHAUST GASES MORE ENERGY THAN THAT WHICH IS NECESSARY TO REACH THE TARGET BOOST PRESSURE.

THE ELECTRIC ENERGY WHICH IS PRODUCED IS PROVIDED TO THE VEHICLE ELECTRIC SYSTEM REDUCING THE ELECTRIC LOAD ON THE ALTERNATORS AND SO THE AUXIALIARY POWER REQUIREMENT, WITH AN OBVIOUS FUEL CONSUMPTION REDUCTION.

MOREOVER, THE TORQUE ABSORBED BY THE ELECTRIC MACHINE ALLOWS THE CONTROL OF THE TURBO SPEED, WITHOUT THE NEED FOR A WASTEGATE OR A VGT.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

INTRODUCTION

HOWEVER, THE POTENTIAL OF THIS KIND OF SYSTEM IS STRONGLY DEPENDENT ON THE DRIVING CYCLE (I.E. REGENERATION PERIODS WHEN THE ELECTRIC MACHINE OPERATES AS A GENERATOR SHOULD BE LONG ENOUGH TO PRODUCE AND STORE THE ENERGY THAT WILL BE REQUIRED TO SPEED-UP THE TURBOCHARGER DURING THE ACCELERATION TRANSIENTS OF THE INTERNAL COMBUSTION ENGINE).

THEREFORE, A DETAILED SIMULATION MODEL IS REQUIRED IN ORDER TO ASSESS THE SYSTEM POTENTIAL.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:

THE ELEGT PROJECT

- RESEARCH PROJECT FUNDED BY THE RESEARCH DIRECTORATE OF THE EUROPEAN UNION COMMISSION
- MULTI NATIONAL / MULTI CULTURAL ORIENTED FINANCING, AIMED TO NATION BUILDING
- PROJECT IS PART OF THE 5th FRAMEWORK PROGRAMME (1998-2002), GROWTH PROGRAMME

CONTRACT N° : 63083
PROJECT N° : G3RD-CT-2002-00788
ACRONYM : ELEGT
TITLE : ELectric Exhaust Gas Turbocharger

CORDIS

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:

THE ELEGT PARTNERS

- PROJECT CO-ORDINATOR : IVECO S.p.A.

PARTNERS :

1) IVECO S.p.A.	(IVECO)	I
2) Iveco Motorenforschung LTD	(IMF)	CH
3) HOLSET Engineering LTD	(Holset)	UK
4) Thien-E-motors LTD	(Thien)	A
5) ATE GMBH	(ATE)	D
6) University of Durham	(Durham)	UK

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:

ELEGT SCHEDULE AND FINANCING

- **PROJECT START DATE :** 2002-July-01
- **DURATION :** 48 months
- **PROJECT END DATE :** 2006-June-30

- FINANCING:
  - EU COMMISSION: 1.45 MILLION EURO
  - SWITZERLAND: 0.67 MILLION CHF
  - INDUSTRY: 1.68 MILLION EURO

- More info at www.cordis.lu , www.aramis-research.ch

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

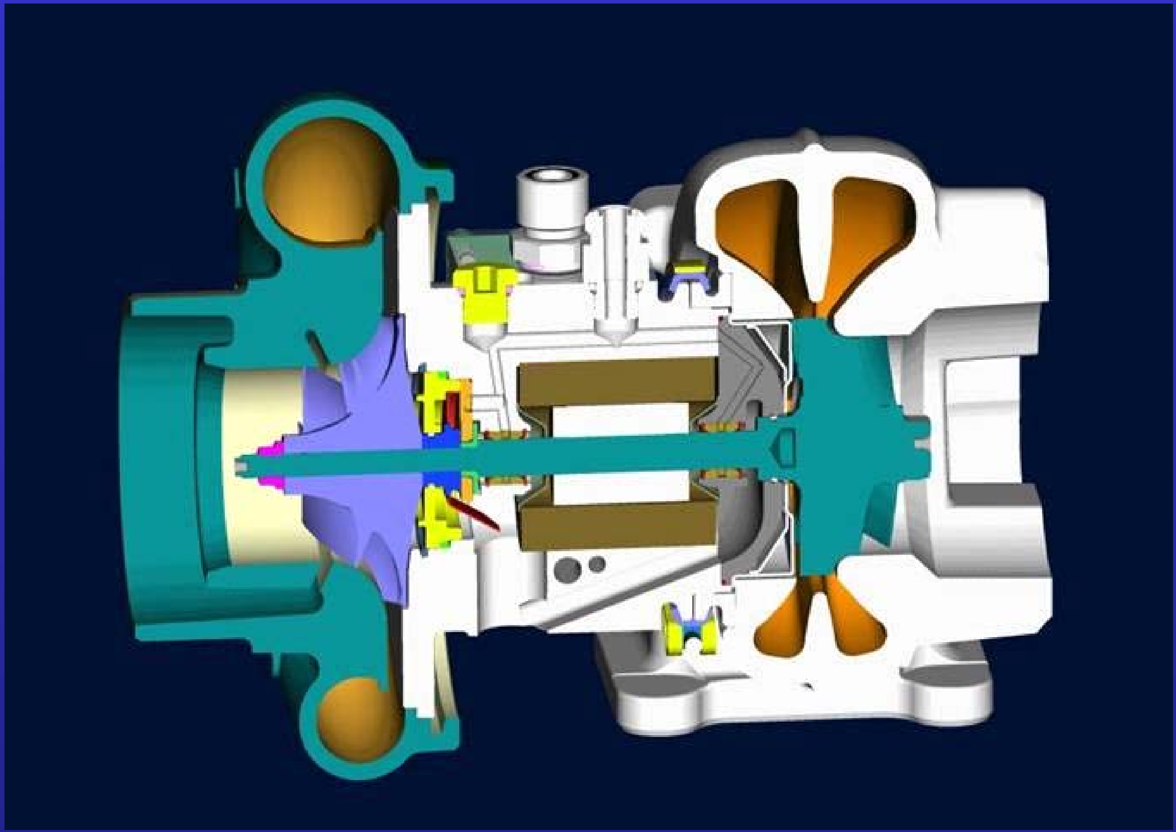
CONTEST:
ELEGT PROJECT MAIN STEPS

- PREVIOUS FULL SYSTEM MODEL, SIMULINK BASED, REALIZED BY DURHAM UNIVERSITY
- SIMULINK MODEL PREDICTED BSFC REDUCTIONS RANGING FROM 5% TO 10% AT ON-HIGHWAY CYCLE BEST CASES REMOVING THE ALTERNATOR
- THE ELEGT GROUP BUILT THE FIRST GENERATION PROTOTYPE (MK1.0), BUT ALREADY DESIGNED THE 2nd GENERATION (MK2.0)
- ELEGT MK1.0 (ACTUALLY MK1.2) HAS BEEN RUN ON A ENGINE TEST CELL ON JUNE 2005
- ELEGT MK2.0 NOT YET AVAILABLE (ENGINE TESTS SCHEDULED FOR FALL 2005)
- DETAILED INTERNAL COMBUSTION ENGINE MODEL COUPLED WITH SIMULINK MODEL OF ELECTRIC SUBSYSTEM REALIZED BY POLITECNICO DI TORINO FOR MK2.0

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:
ELEGT PROJECT MAIN STEPS

ELEGT Mk1.0

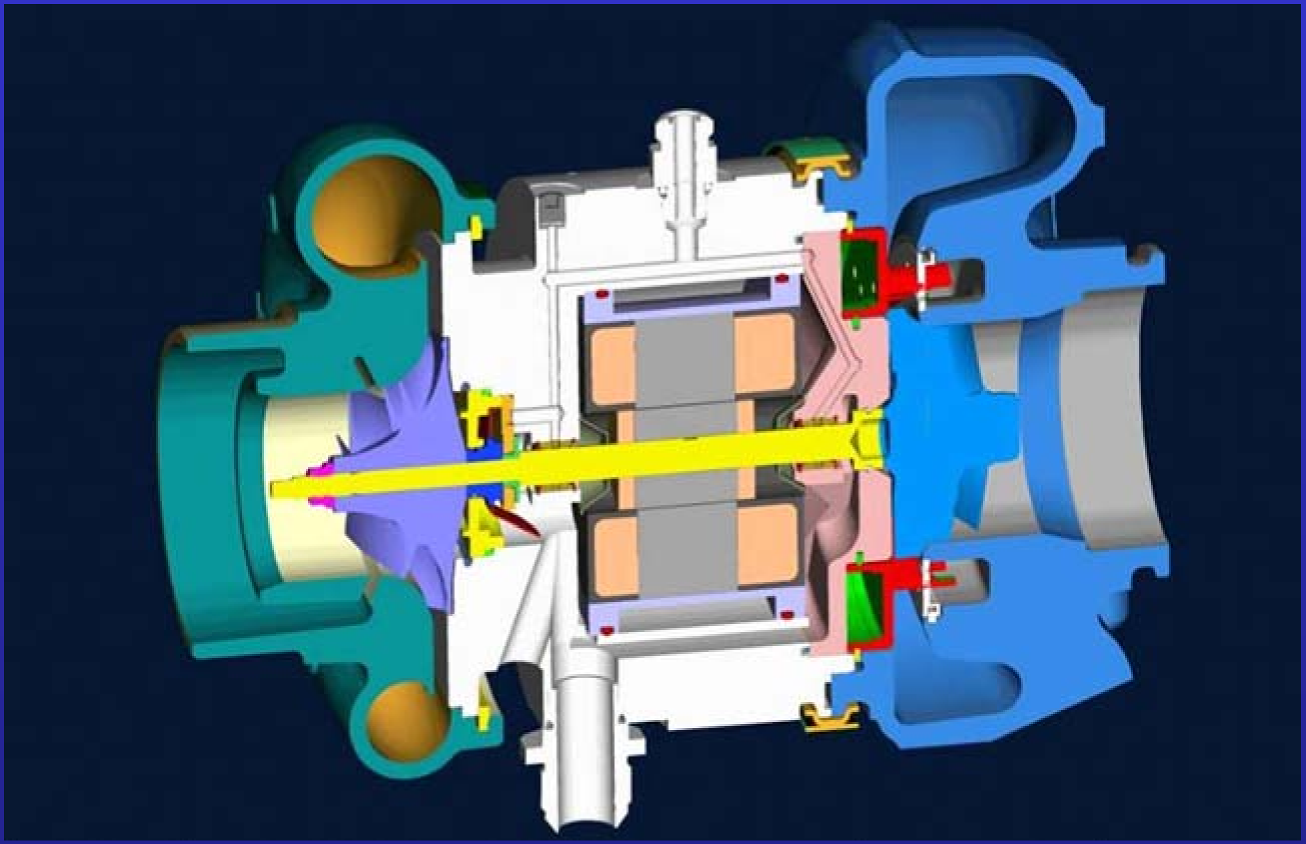


ELEGT Mk1.0:
- ASYNCRONOUS, WATER COOLED;
- TURBO ASSIST. MAX POWER 6,3 kW for 3s (15% duty cycle);
- GENERAT. MODE ALLOWED ONLY INTERMITTENT.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:
ELEGT PROJECT MAIN STEPS

ELEGT Mk2.0



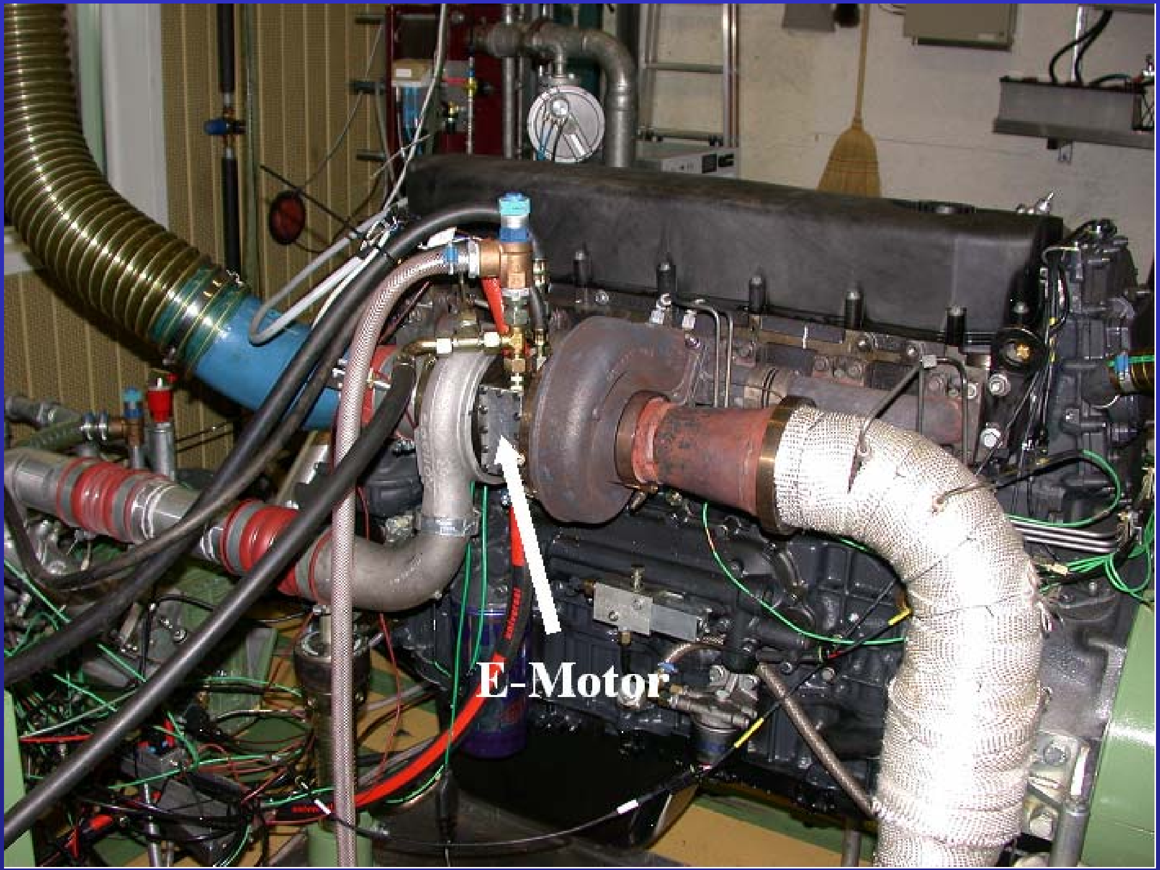
ELEGT Mk2.0:

ENHANCED COOLING ALLOWS AN INCREASE IN MAX TEMP. AND CONTINOUS GENERATION, ENLARGED TURBINE HOUSING ALLOWS BIGGER ROTOR

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

CONTEST:
ELEGT PROJECT MAIN STEPS

ELEGT MK1.2 ON ENGINE TEST RIG



- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL

CURRENTLY IN PRODUCTION HD DIESEL ENGINE (IVECO CURSOR 8) WITH VGT WAS USED AS A REFERENCE

MAIN ENGINE FEATURES

IVECO CURSOR 8

CYCLE	DIESEL 4 STROKE
N° CYLINDERS	6 IN LINE
DISPLACEMENT [dm^3]	7.8
BORE [mm]	115
STROKE [mm]	125
COMPRESSION RATIO	17:1
MAXIMUM TORQUE [Nm]	1280 AT 1080 RPM
MAXIMUM POWER [kW]	259 AT 2400 RPM
AIR INTAKE SYSTEM	SINGLE STAGE TURBOCHARGER (WITH VGT AND AFTERCOOLER)

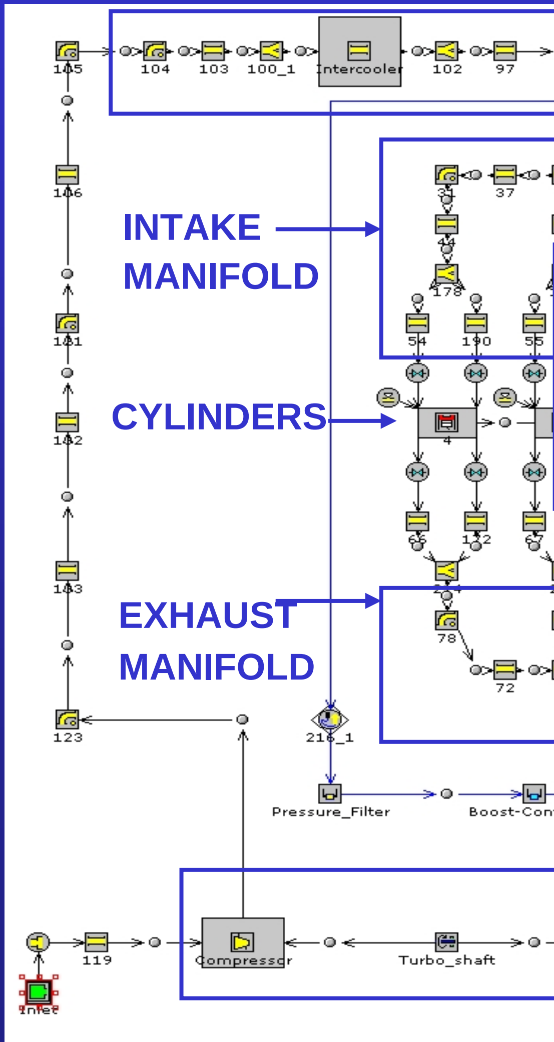
- MAX. BMEP 20.6 BAR
- SPEC. OUTPUT 33 KW / dm^3

SEVERAL DIFFERENT APPLICATIONS (E.G. TRUCKS, URBAN BUSES, HARVESTERS, ETC.).

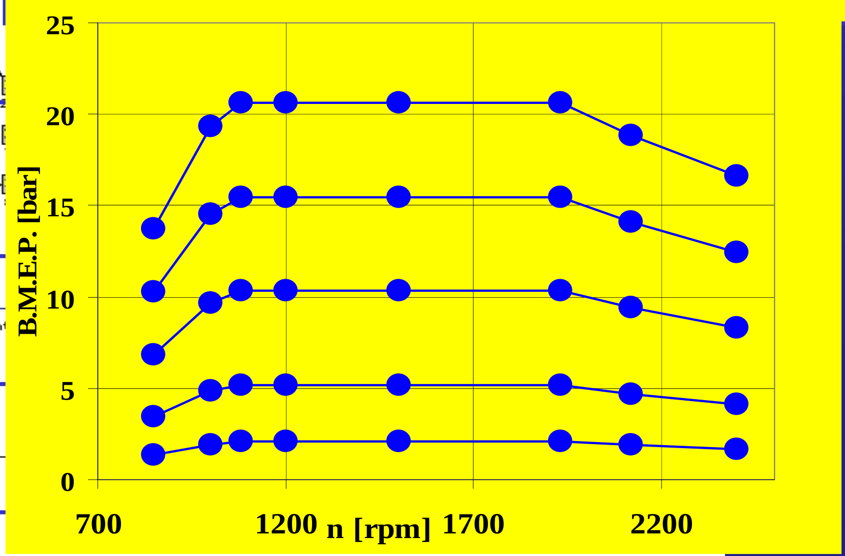
- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL

COMPUTER SIMULATIONS WERE CARRIED OUT USING **GT-POWER**, A ONE-DIMENSIONAL CODE DEVELOPED BY GAMMA TECHNOLOGIES FOR ENGINE PERFORMANCE PREDICTION



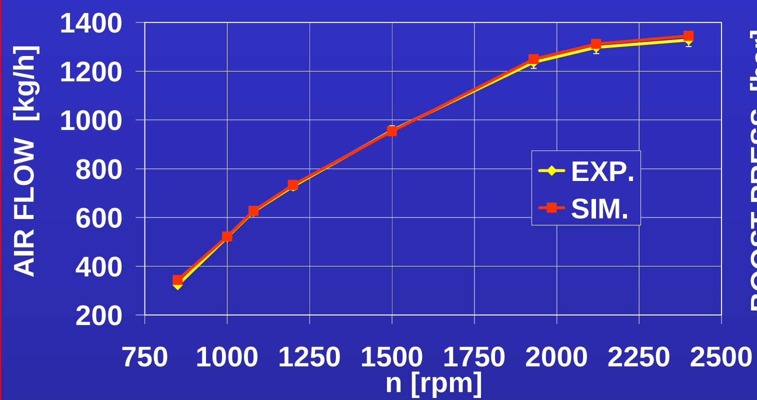
8 ENGINE SPEEDS AND 5 LOAD LEVELS FOR A TOTAL OF 40 OPERATING POINTS USED FOR MODEL VALIDATION



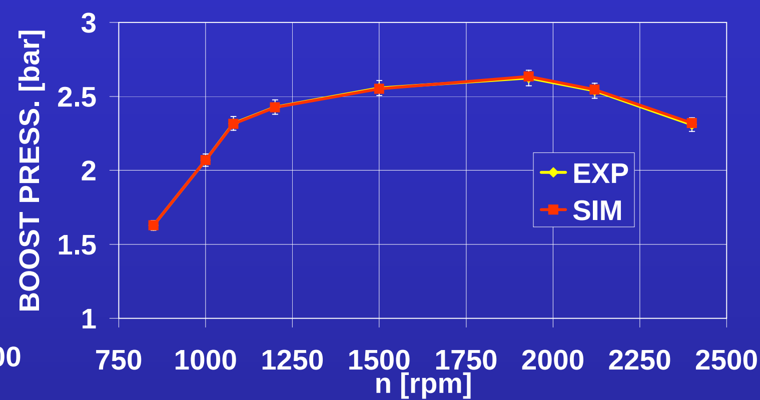
- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL: ENGINE MODEL VALIDATION FULL LOAD OPERATING CONDITIONS

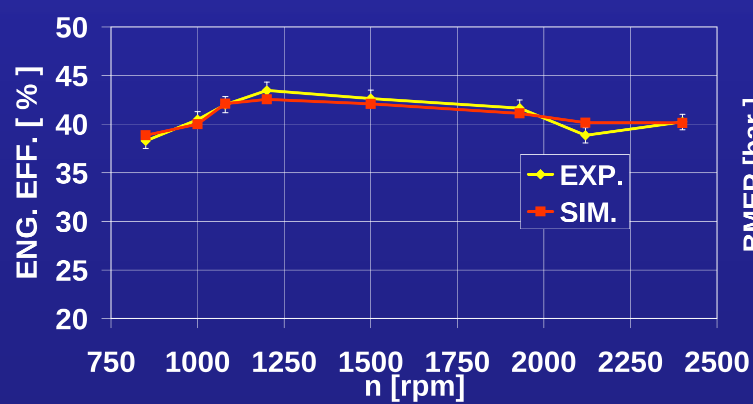
AIR MASS FLOW



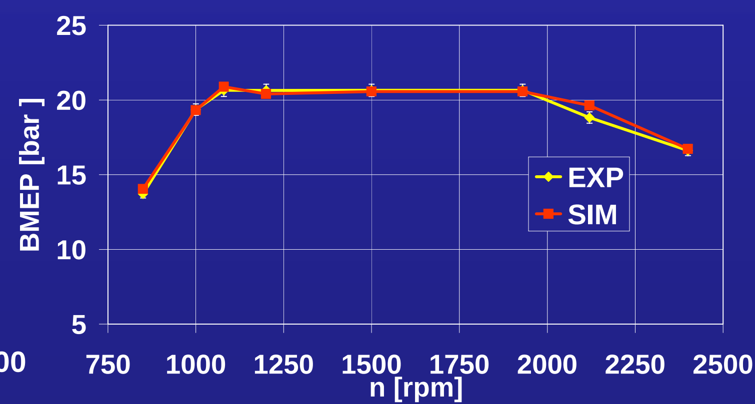
BOOST PRESSURE



ENGINE EFFICIENCY



BMEP



- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL:

VEHICLE MODEL

SIMULATED VEHICLE :

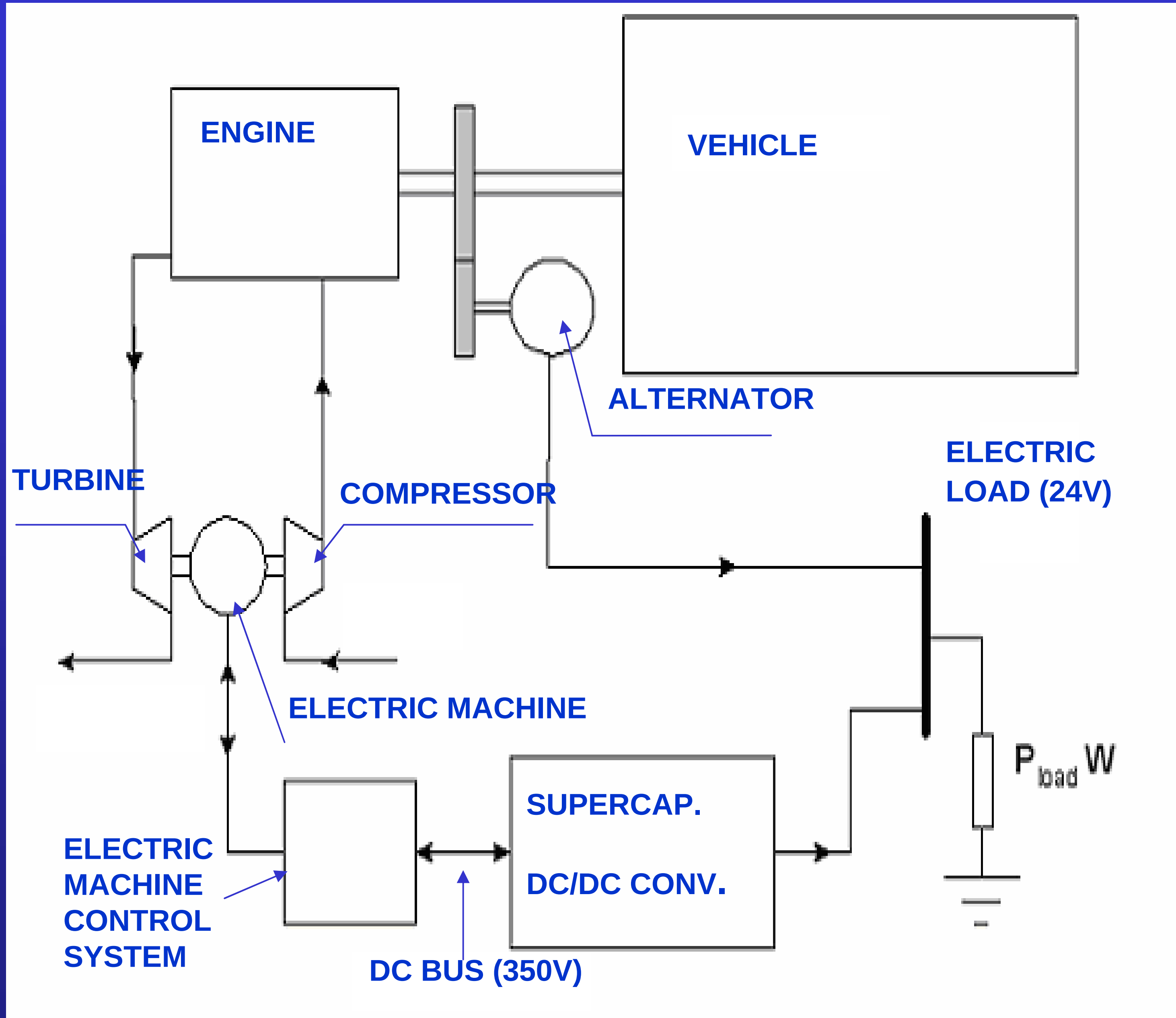
URBAN BUS (12 tons UNLOADED, 16.5 tons FULL LOADED)

AUTOMATIC GEARSHIFT WITH TORQUE CONVERTER

COUPLED ENGINE-VEHICLE MODEL VALIDATION

DRIVING CYCLE	EXP. FUEL CONS. [L/100KM]	SIM. FUEL CONS. [L/100KM]
SORT1	49.2 ÷ 46.8	44.7
SORT2	42.2 ÷ 38.2	39.0

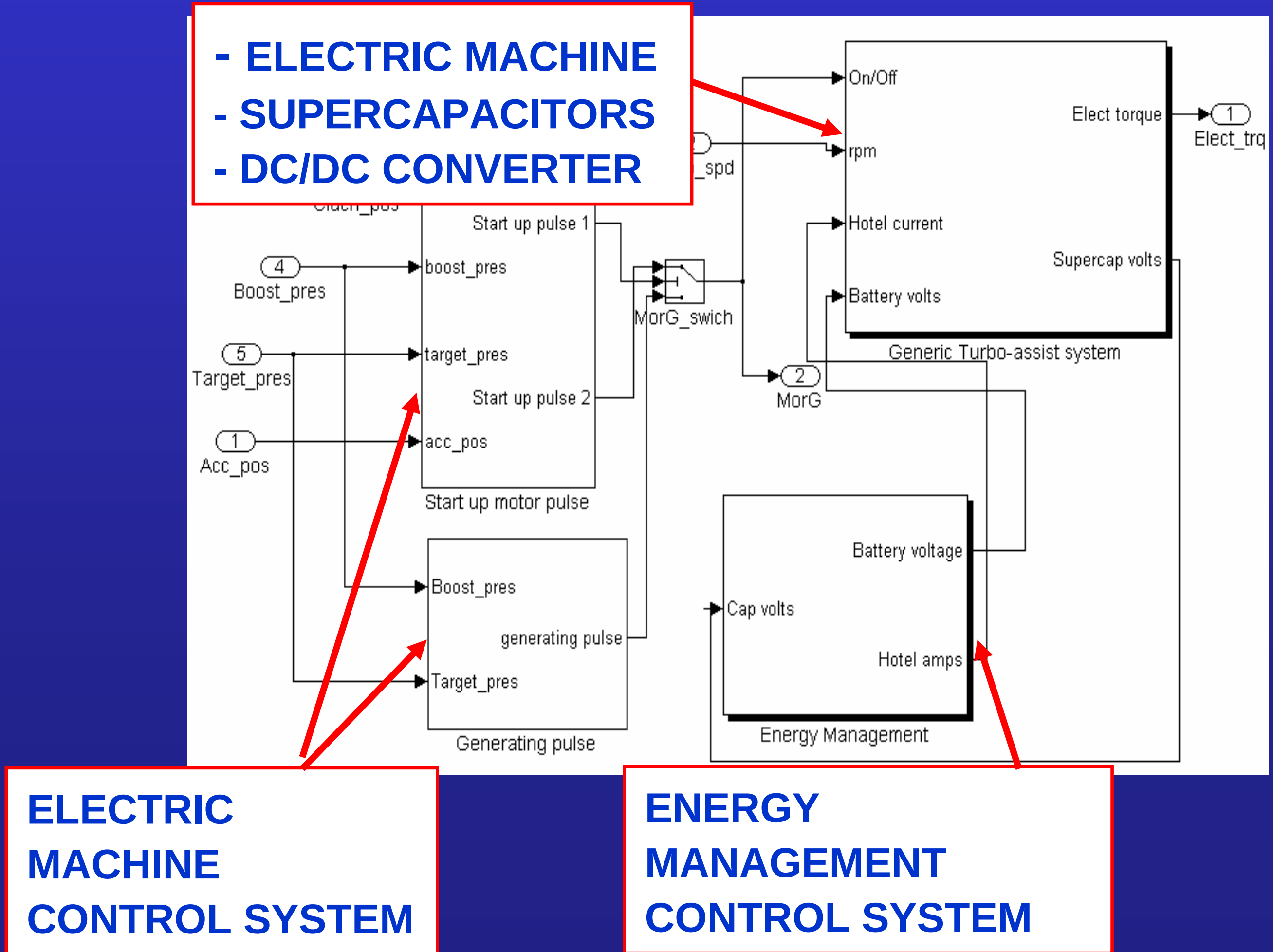
BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT SYSTEM ARCHITECTURE



- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT SYSTEM ARCHITECTURE

SIMULINK MODEL OF ELECTRIC SUBSYSTEMS (UNIV. OF DURHAM) COUPLED WITH ENGINE AND VEHICLE GT-POWER MODEL (POLITECNICO DI TORINO)



- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL: ELECTRIC MACHINE MAIN FEATURES

MOTOR	TORQUE & POWER	CONST. TORQUE (1 Nm) UP TO 60.000 rpm, CONST. POWER (6.3 kW) UP TO 120.000 rpm
	USAGE	INTERMITTENT (3 s USE IN A 20 s CYCLE)
GENERATOR	TORQUE & POWER	CONSTANT GENERATING POWER (7.6 kW)
	USAGE	CONTINUOUS
MOTOR/ GENERATOR	VOLTAGE	350 Volts
	MAXIMUM DESIGN SPEED	130.000 rpm
	MAXIMUM OVERSPEED	143.000 rpm

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM

AT FIRST THE ELECTRICAL POWER GENERATED BY THE ELEGT SYSTEM IS USED TO CHARGE THE SUPERCAPACITORS. WHEN THEIR SOC (STATE OF CHARGE) IS HIGHER THAN 0.65 THEY START TO PROVIDE TO THE VEHICLE ELECTRIC SYSTEM THE POWER USUALLY GENERATED BY ONE ALTERNATOR.

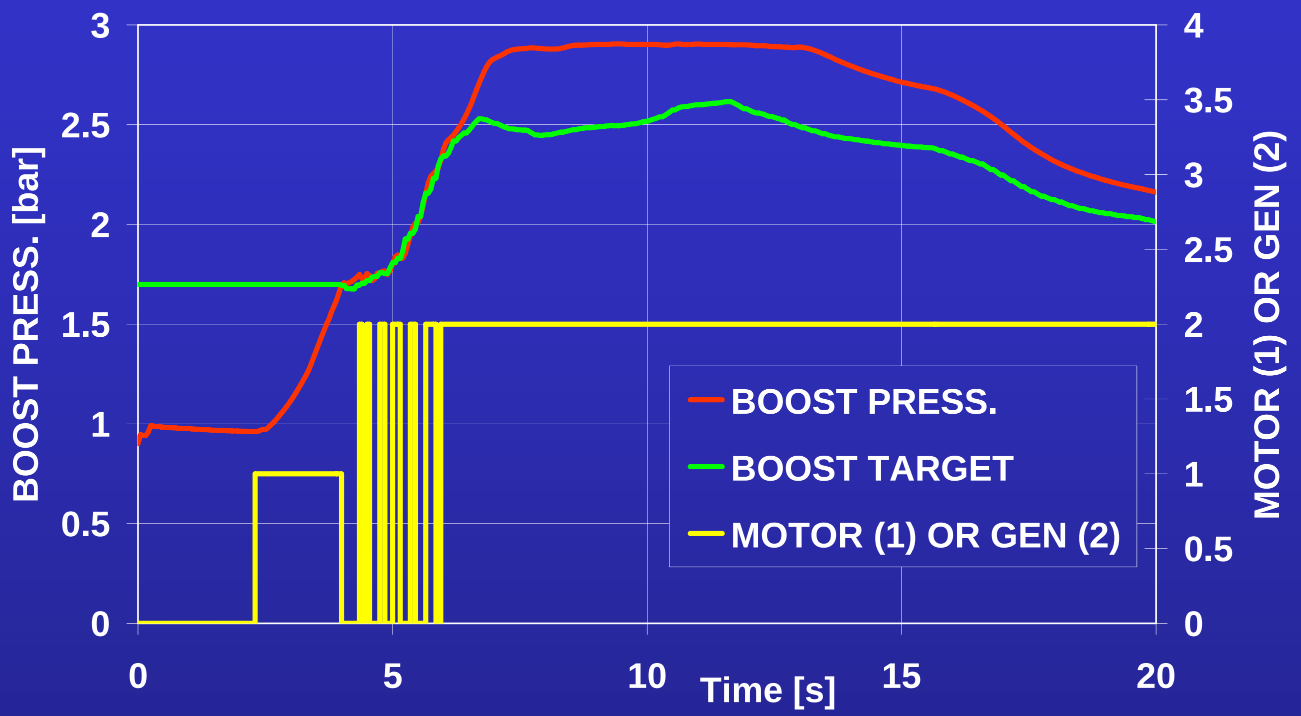
IF THE SYSTEM GENERATES CONTINUOUSLY THE SOC LEVEL CONTINUES TO INCREASE. WHEN IT RISES ABOVE THE 0.85 LEVEL, ALSO THE SECOND ALTERNATOR ELECTRIC POWER CAN BE SAVED.

ON THE CONTRARY IF THE SYSTEM GENERATES DISCONTINUOUSLY OR DOESN'T GENERATE AT ALL THE SOC LEVEL DECREASES AND WHEN IT GOES BELOW A LOWER LIMIT THE LOAD REQUIRED TO THE SUPERCAPACITORS IS SET TO ZERO, AS, CONSEQUENTLY, THE POWER ADDED TO THE ENGINE.

THE INSTANTANEOUS ELECTRIC POWER PROVIDED BY THE ELEGT SYSTEM IS CALCULATED DURING THE WHOLE DRIVING CYCLE.

- Introduction
- Contest
- Building the engine and vehicle model
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

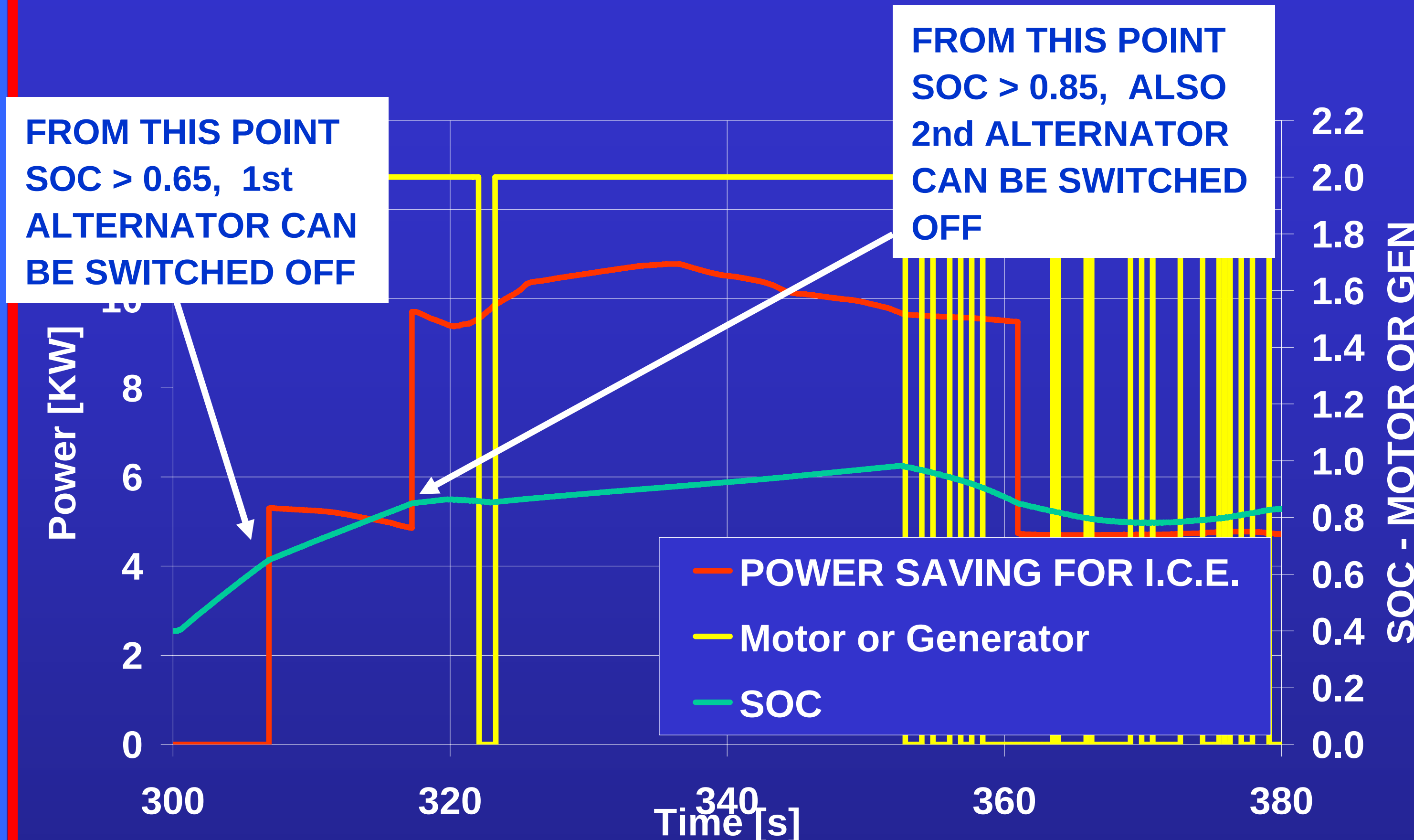
BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM



EXAMPLE OF CONTROL STRATEGY DURING THE FIRST 20 s OF THE HWFET DRIVING CYCLE

- Introduction
- Contest
- **Building the engine and vehicle model**
- Analysis of possible fuel consumption reductions and performance enhancements
- Conclusions
- Continuation

BUILDING THE ENGINE AND VEHICLE MODEL: ELEGT CONTROL SYSTEM



EXAMPLE OF CONTROL STRATEGY DURING A PERIOD OF 80 s IN THE HWFET DRIVING CYCLE

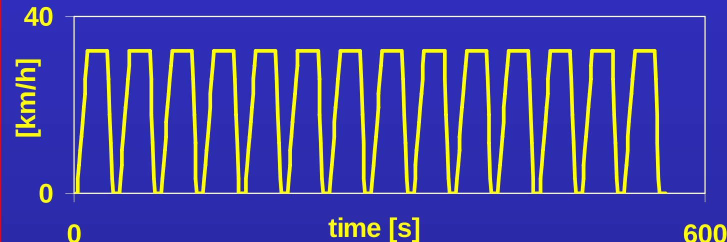
- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

CONSIDERED DRIVING CYCLES

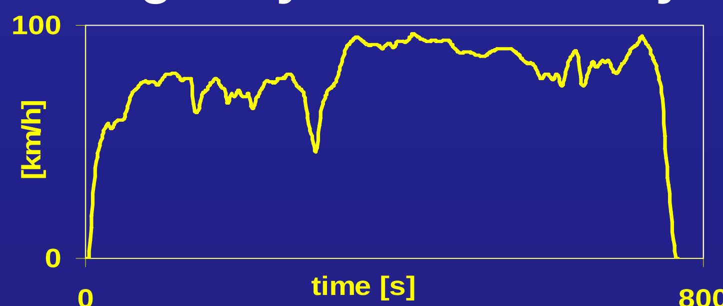
CBD

Central Business District



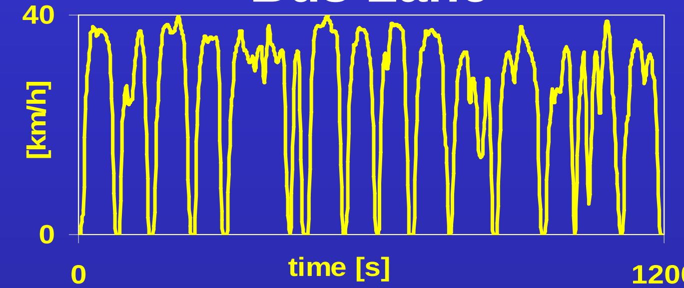
HWFET

Highway Fuel Economy



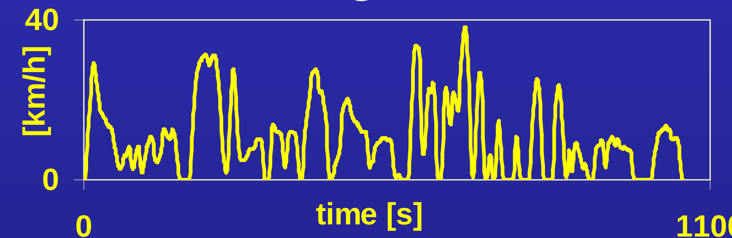
TRL03

Bus Lane



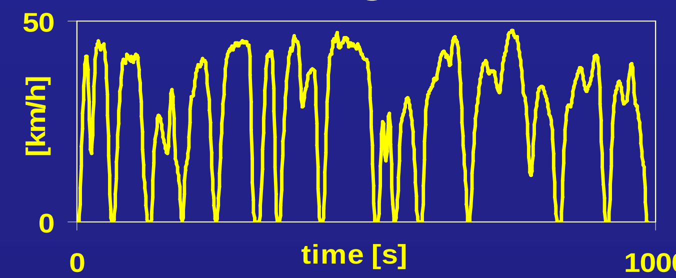
TRL08

Bus in congested traffic



TRL09

Bus in non-congested traffic



- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

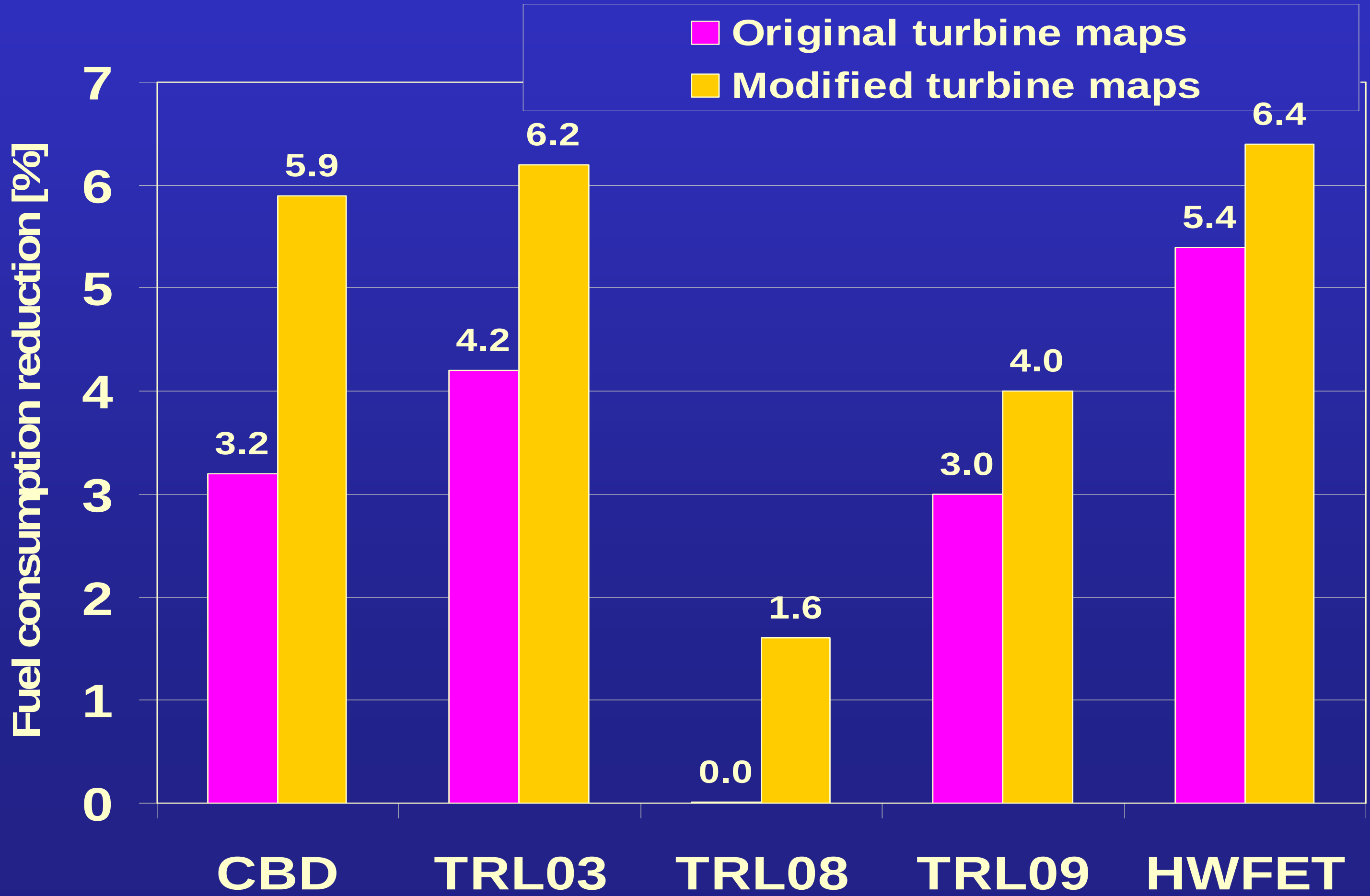
- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

MODIFIED TURBINE MAPS



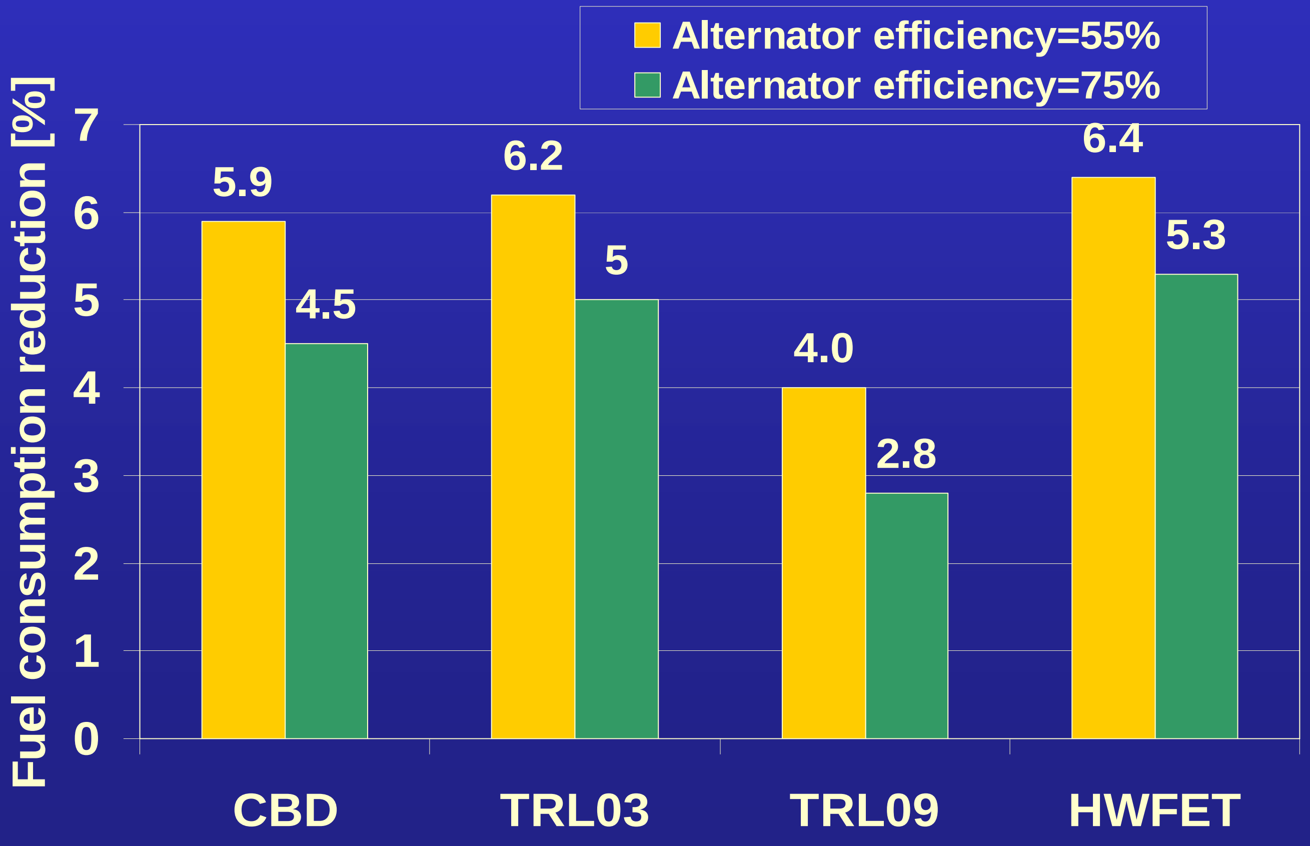
- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

SIMULATION RESULTS

FULL LOADED VEHICLE (16.5 tons)

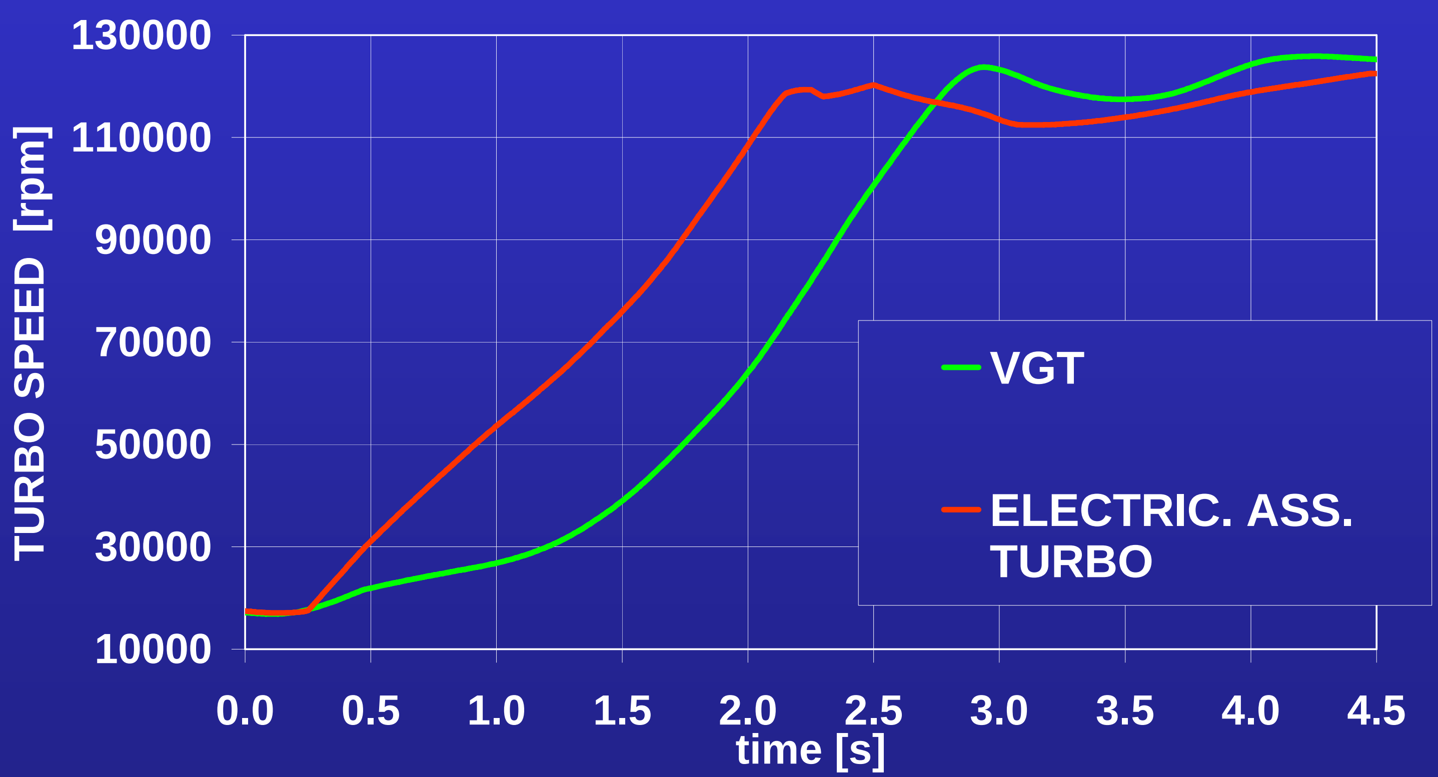
ALTERNATOR AVER. EFFIC. 75% INSTEAD OF 55%



- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

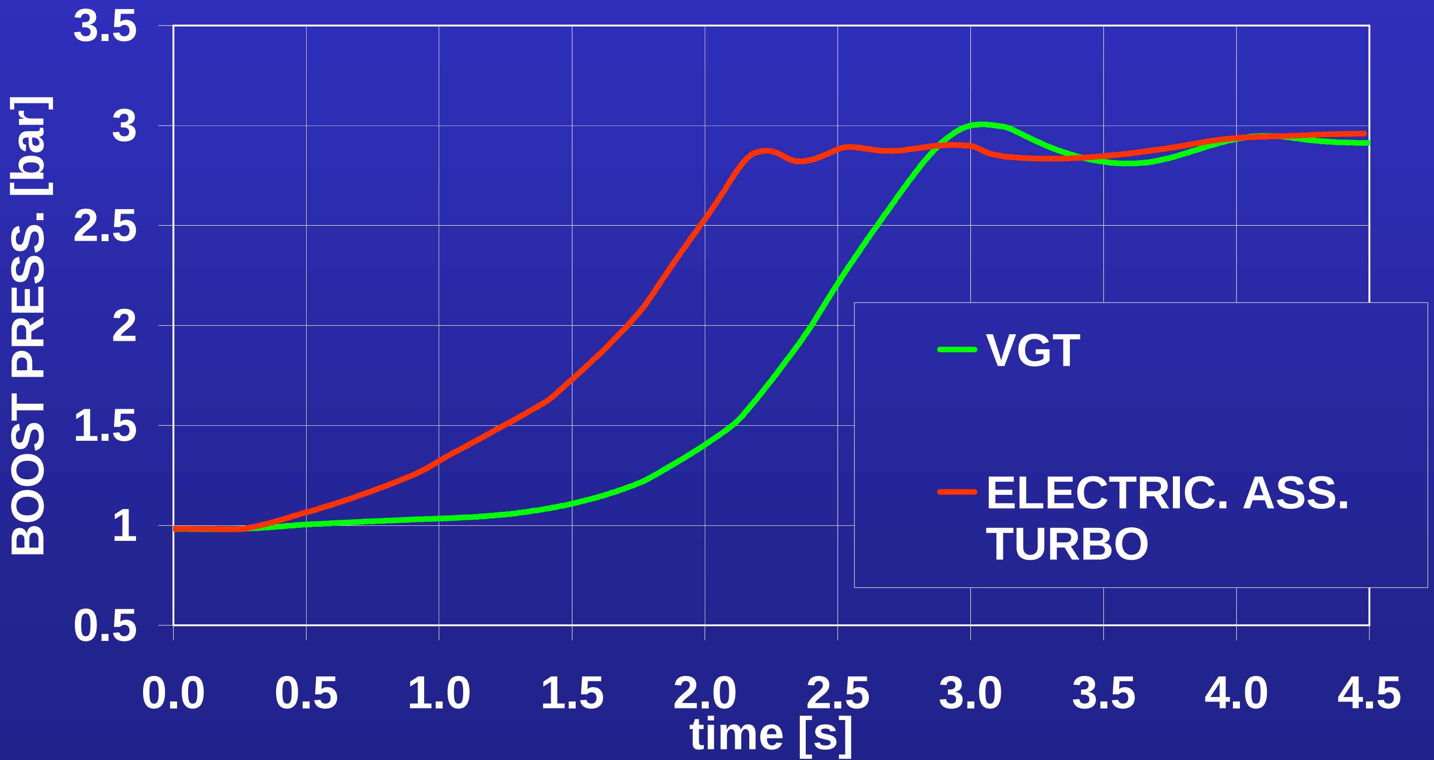
TURBO LAG REDUCTION: TURBO SPEED



- Introduction
- Contest
- Building the engine and vehicle model
- **Analysis of possible fuel consumption reductions and performance enhancements**
- Conclusions
- Continuation

ANALYSIS OF POSSIBLE FUEL CONSUMPTION REDUCTIONS AND PERFORMANCE ENHANCEMENTS

TURBO LAG REDUCTION: BOOST PRESSURE



CONCLUSIONS

MAIN FINDINGS WERE THE FOLLOWINGS:

- THE ELEGT SYSTEM ALLOWS A FUEL CONSUMPTION REDUCTION FROM 1.5% TO 5.5% DEPENDING ON THE DRIVING CYCLE;

- THESE VALUES COULD BE INCREASED BY CONSIDERING AN “ON PURPOSE” DESIGNED TURBINE;

- FUEL SAVINGS ARE STILL APPRECIABLE EVEN IF BETTER EFFICIENCY ALTERNATORS ARE CONSIDERED;

- SUBSTANTIAL IMPROVEMENTS DURING THE ACCELERATION TRANSIENTS CAN BE ACHIEVED (ALREADY CONFIRMED BY FIRST EXPERIMENTAL TESTS ON MK 1.2 SYSTEM)

PROJECT CONTINUATION

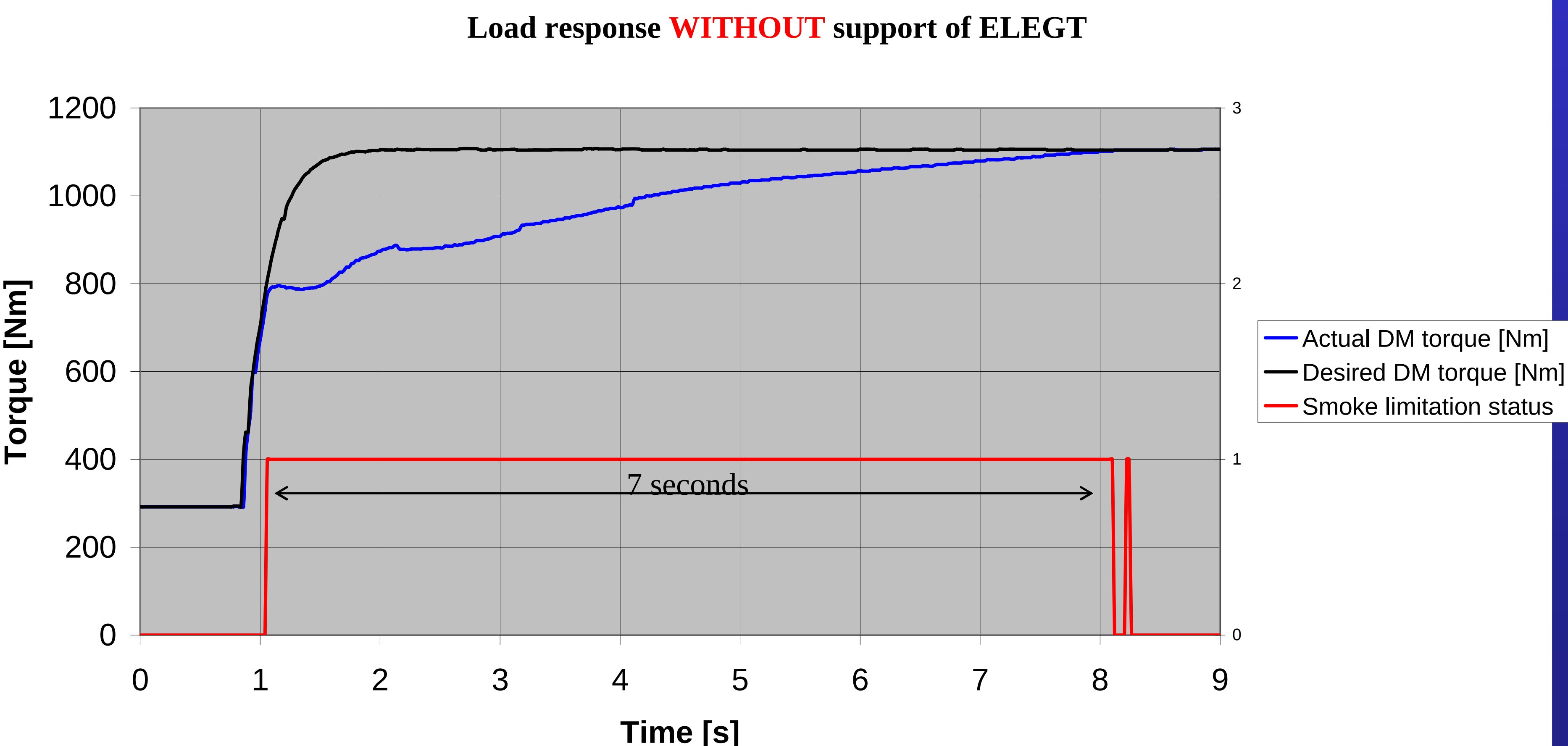
- EXPERIMENTAL TESTS ON MK2.0
- SYSTEM OPTIMIZATION STUDY (TURBINE, VEHICLE, SUPERCAPACITORS)
- FURTHER INVERTER DEVELOPMENT

EXPERIMENTAL RESULTS (MK1.2 system)

Acceleration transient without ELEGT

Drivers‘ torque demand steps from 300 to 1100 Nm.

Actual possible torque is limited by ECU (smoke limitation)



EXPERIMENTAL RESULTS (MK1.2 system) Acceleration transient with ELEGT

(with the same Drivers‘ torque demand as before)

Actual possible torque rises more rapidly as before